Data Assimilation for Doppler Radar/Shipboard Systems

Allen Zhao
Naval Research Laboratory
Monterey, California 93943
phone: (831) 656-4700 fax: (831) 656-4769 email: zhao@nrlmry.navy.mil

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http://www.nrlmry.navy.mil

LONG-TERM GOALS

Our goal is to develop a high-resolution data assimilation capability that can provide the U.S. Navy with improved analyses and forecasts of the atmospheric conditions with sufficient detail and accuracy for supporting the Navy mission in threat detection, weapons, and weather safe operations. The data assimilation system will utilize all available weather information, such as Doppler radar, in situ, and remotely sensed observations. The system will run efficiently and generate a detailed analysis of the atmosphere with sufficient accuracy to predict Electro-Magnetic/Electro-Optical (EM/EO) propagation and target area weather conditions. This information can then be fed back to SPY-1 radar and other weapon system operators to improve detection capabilities.

OBJECTIVES

The objective of this research is to build a set of comprehensive data assimilation algorithms for the on-scene (OS) version of the Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS™[1]), and at the same time, investigate the impact of high-resolution data assimilation on mesoscale numerical weather prediction. This data assimilation scheme will be able to analyze mesoscale weather by applying sophisticated analysis procedures capable of ingesting the information from Doppler radar, satellite, and other remote sensors. The primary focus of this effort will be to design a system that optimally utilizes the available weather information such as SPY-1 Doppler radar for the NOWCAST system and for initializing COAMPS-OS™.

APPROACH

The Naval Research Laboratory (NRL) and the University of Oklahoma (OU) are jointly developing a mesoscale variational data assimilation system (3.5DVAR). This 3.5DVAR system uses the background fields provided by atmospheric predictions from COAMPS at non-synoptic times and/or by analyses from the newly developed NRL Atmospheric Variational Data Assimilation System (NAVDAS) at synoptic times. Simplified adjoint methods are used to achieve the high computational efficiency needed to assimilate high-resolution data from Doppler radars (including SPY-1 Tactical Environmental Processor) in space and time. The analysis increment fields are expressed by B-spline basis functions to optimally filter noise while the analysis is performed directly on the COAMPS grid. The assimilation time window is synchronized with COAMPS integration time steps and radar volumetric scans to enhance the coupling of the model with the data. To compliment the radar

[1] COAMPS™ and COAMPS-OS™ are trademarks of the Naval Research Laboratory.

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14. ABSTRACT
Our goal is to develop a high-resolution data assimilation capability that can provide the U.S. Navy with improved analyses and forecasts of the atmospheric conditions with sufficient detail and accuracy for supporting the Navy mission in threat detection, weapons, and weather safe operations. The data assimilation system will utilize all available weather information, such as Doppler radar, in situ, and remotely sensed observations. The system will run efficiently and generate a detailed analysis of the atmosphere with sufficient accuracy to predict Electro-Magnetic/Electro-Optical (EM/EO) propagation and target area weather conditions. This information can then be fed back to SPY-1 radar and other weapon system operators to improve detection capabilities.

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assimilation system, a separate cloud analysis package was adapted for COAMPS from the OU Advanced Regional Prediction System (ARPS). The ARPS Data Analysis System (ADAS) is used to analyze high-resolution geostationary satellite observations (such as the GOES infrared and visible imagery), surface cloud observations, and reflectivity from radars. The ADAS cloud analysis provides estimates of cloud water and ice over a much larger region than is possible from using the 3.5DVAR system with the radar data alone. To ensure the accuracy of the cloud analysis, a cloud verification system has been developed to automatically verify the 3-D cloud products against satellite and surface observations.

WORK COMPLETED

As planned, research in the fiscal year 2003 has been focused on studying the impact of assimilated wind and cloud information from Doppler radar and other remotely sensed data on mesoscale analysis and prediction. For this purpose, several efforts have been made. First, both the 3.5DVAR radar wind analysis system and the ADAS cloud analysis system have been enhanced to use radar data from multiple radars instead of from single radar. While the main purpose of this improvement is to increase the radar data coverage, the accuracy of retrieved information in areas covered by multiple radars is also improved due to the increase in data resolution and number of wind components observed by different radars that cover the area. More importantly, this enhancement makes it possible for the system to simultaneously use data from different types of radars (coastal, mobile, and shipboard radars) to increase both data coverage and accuracy, which is very important to the U.S. Navy. Improvements of the systems also include the use of the multivariate background error covariance and the recursive B-spline filter recently developed by Xu and Gong (2003) in the 3.5DVAR radar wind analysis system to improve the wind analysis from radar observations. Second, the data assimilation system has been tested extensively with cases from various synoptic conditions, including large-scale frontal system and isolated thunderstorms. Two research areas have been studied with considerable effort: one is the value of observed radar radial winds added to three-dimensional wind analysis, and another is the impact of the retrieved information on model forecast. Further discussions on these studies will be given in the next section.

In addition to data assimilation studies, several system developments have been done in combined efforts with the NOWCAST project. The first one is the integration of the ADAS cloud analysis system and the cloud verification system into COAMPS-OS™ 1.2 for operation. This allows ADAS to provide NRL NOWCAST system with three-dimensional clouds and derived products and, in the near future, provide the COAMPS model with improved initial cloud conditions in real-time. The second one is the modification of both the COAMPS 3.0 and 3.5DVAR to establish a direct link between these two systems. This step is necessary for the development of real-time capability of radar data assimilation at NRL.

Radar data processing and quality control are also critical to this research. In the last year, significant progress has been made in these areas. Software has been developed to ingest and display SPY-1 and SWR Doppler radar data and other shipboard or DoD/NWS land-based Doppler radar data stored in Universal Format (UF). Arrangements have been made to obtain and integrate the Radar Echo Classifier (REC) algorithm with the MIT/Lincoln Laboratory Data Quality Assurance algorithm for use at NRL. In addition, the Principal Component Analysis QC algorithm created by Dr. Harasti is under development and will be employed as a final QC step to remove residual clutter and artifacts. The Radar Echo Classifier (REC), which was originally formulated for WSR-88D data, is being tested for data quality control of SPY-1 and SWR Doppler radar data.

RESULTS

As mentioned earlier, one of the major research efforts during the last year has been the investigation of the values of radar observed radial winds added to the three-dimensional wind analysis. Several case studies have been conducted for this purpose. As an example, we will show a squall line case from 9 – 10 May 2003 in Virginia and North Carolina. In this study, radar radial velocities were collected during the storm period from three radars at Norfolk, VA, Raleigh and Morehead City, NC, respectively. The COAMPS model was run with 5 km resolution to provide first guess fields for wind retrieval and the 3.5DVAR system was used to retrieve the three-dimensional winds. Figure 1 gives an example of vertical cross-section of wind increments (wind analyses subtracted by first guess fields, which reflect the impact of observed radar radial velocity on wind analyses) inside the storm system at 00 UTC 10 May 2003. Areas of increased upward motion have been found inside the storms in figure 1. It was also found that most changes in wind analysis caused by radar data assimilation occurred above 1 km level. This effect was likely caused by the lack of radar observations near the surface. Even though, remarkable impact of the observed radar radial velocity on lower level convergence has been found in almost all the case studies we had. To show this, the maximum convergence increments below 500 hPa were calculated from the retrieved wind increments from the same case and given in figure 2. The results show three convergence increment centers, with two of them associated with the storm systems. This is an indication that radar observations of radial velocity have a positive impact on increasing the lower level convergence of the storm system as expected.

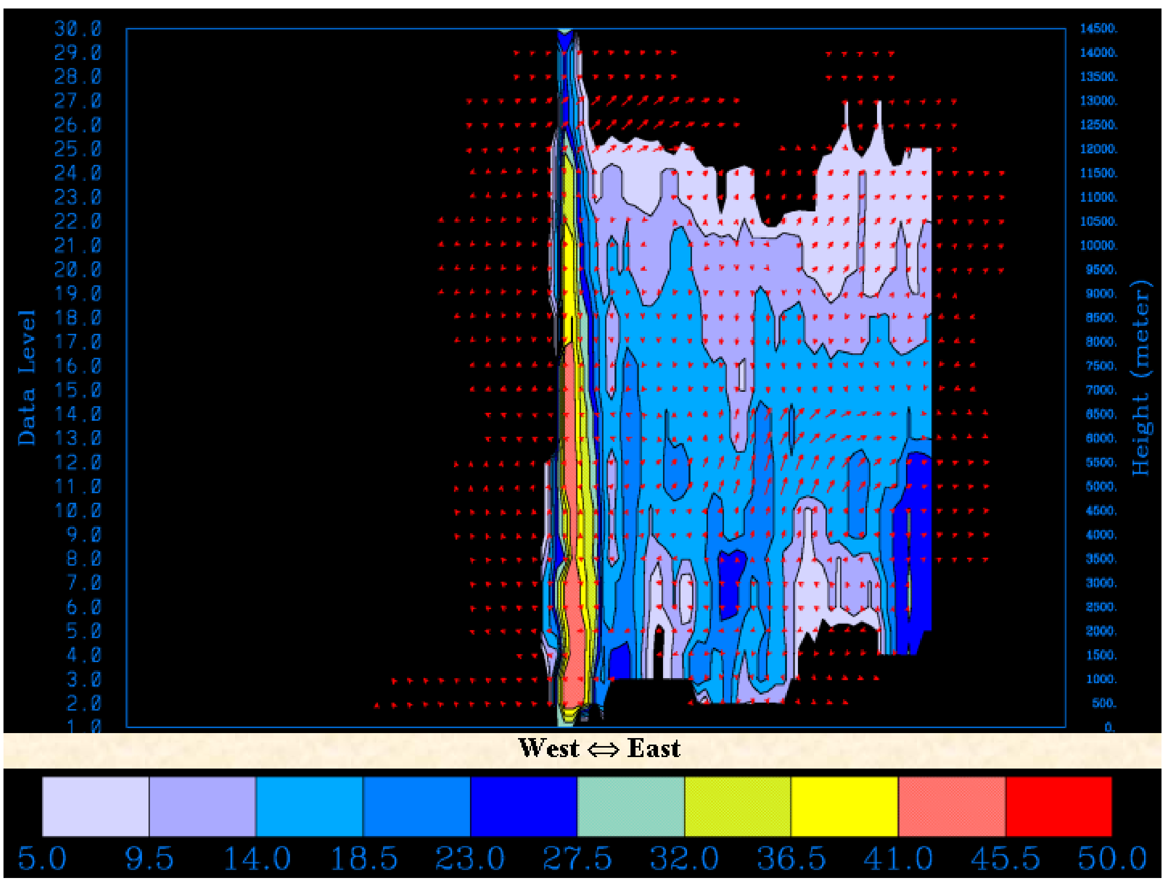

Figure 1. Vertical cress-section of observed radar reflectivity (dBZ) and retrieved wind increments (wind analysis subtracted by first guess winds) at 00 UTC 10 May 2003.

The impact of radar wind assimilation on model forecast was also studied by assimilating the retrieved winds, together with other observations, into COAMPS to initialize the model's initial fields. The same squall line case was again selected for demonstrating this study. Two 12-hour COAMPS forecasts were conducted, both with 5 km resolution, starting at 00 UTC 10 May 2003, one with radar retrieved winds in model initial conditions (EXP) and one without (CNTL). Figure 3 gives the horizontal wind differences between EXP and CNTL at 250 hPa and 500 hPa levels, respectively, at 01 UTC 10 May. It can be seen that the changes in model first-hour wind forecast caused by the inclusion of radar winds in data assimilation were significant, with increased northern wind components at upper levels (250 hPa) and southern wind components at mid levels (500 hPa), which consequently increased the instability of the atmosphere. To further investigate the change of radar data assimilation impact on model forecast with forecast time, root-mean-square (RMS) differences of horizontal winds (u, v) and temperature (T) between EXP and CNTL were also calculated over the whole three-dimensional domain as a function of forecast time. Three interesting things have been found. First, at the beginning of model forecast, the assimilation of radar wind data into COAMPS caused remarkable changes not only in model dynamic fields, but also in thermodynamic fields through the model dynamic balance processes. Second, the changes in v-component were larger than those in u-component. This was probably just for this particular case where the storms were moving in the north-south direction. Third, the impact of radar wind data assimilation on model forecast, however, was decreasing during the first six hours of model integration. Three reasons are thought to be responsible for this decrease: model adjustment, storm disappearance from the model domain, and the effect of model boundary conditions. While changing the data assimilation procedures can modify model adjustment, the storm disappearance from the model domain is case-dependent. The effect of model boundary conditions is however unavoidable for high-resolution, regional-scale model data assimilation. The best way to overcome the influence of boundary conditions is to increase the domain size, or to develop an rapid-update-cycle data assimilation system with an update cycle of one or three hours.

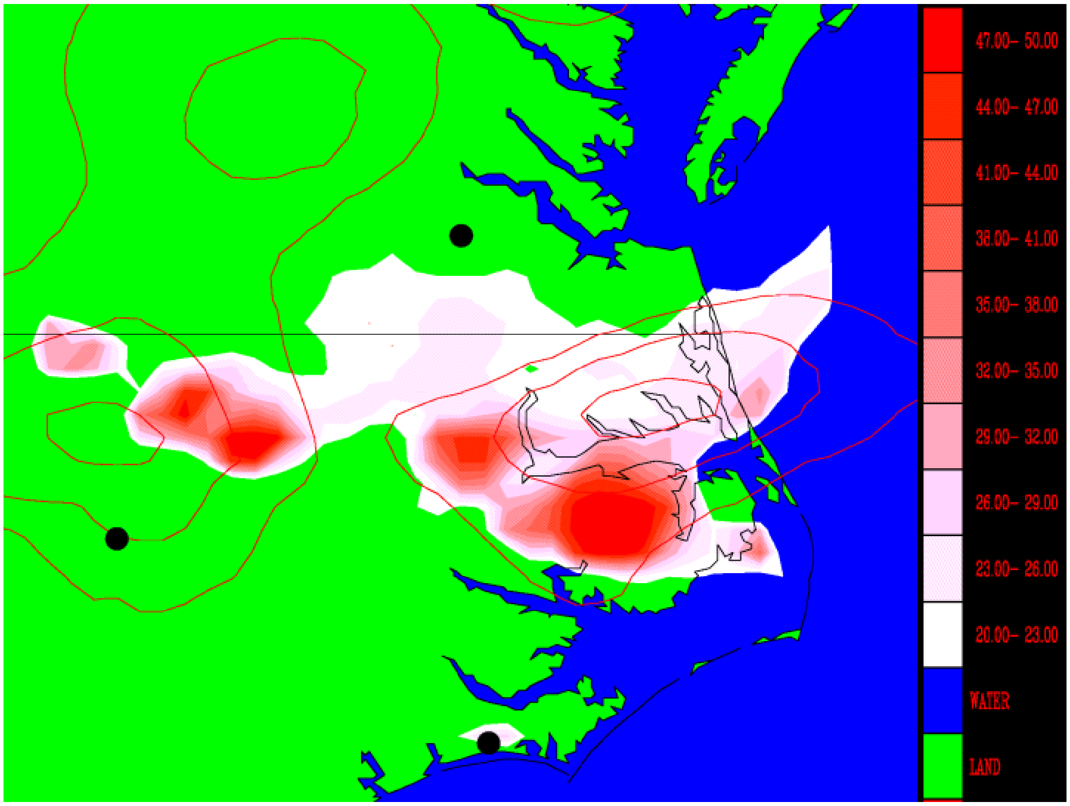

Figure 2. Observed composite radar reflectivity (shaded areas, in dBZ) and maximum convergence increments (contours with interval of 3.0 x $10^{-5}s^{-1}$) calculated from wind increments below 500 hPa.

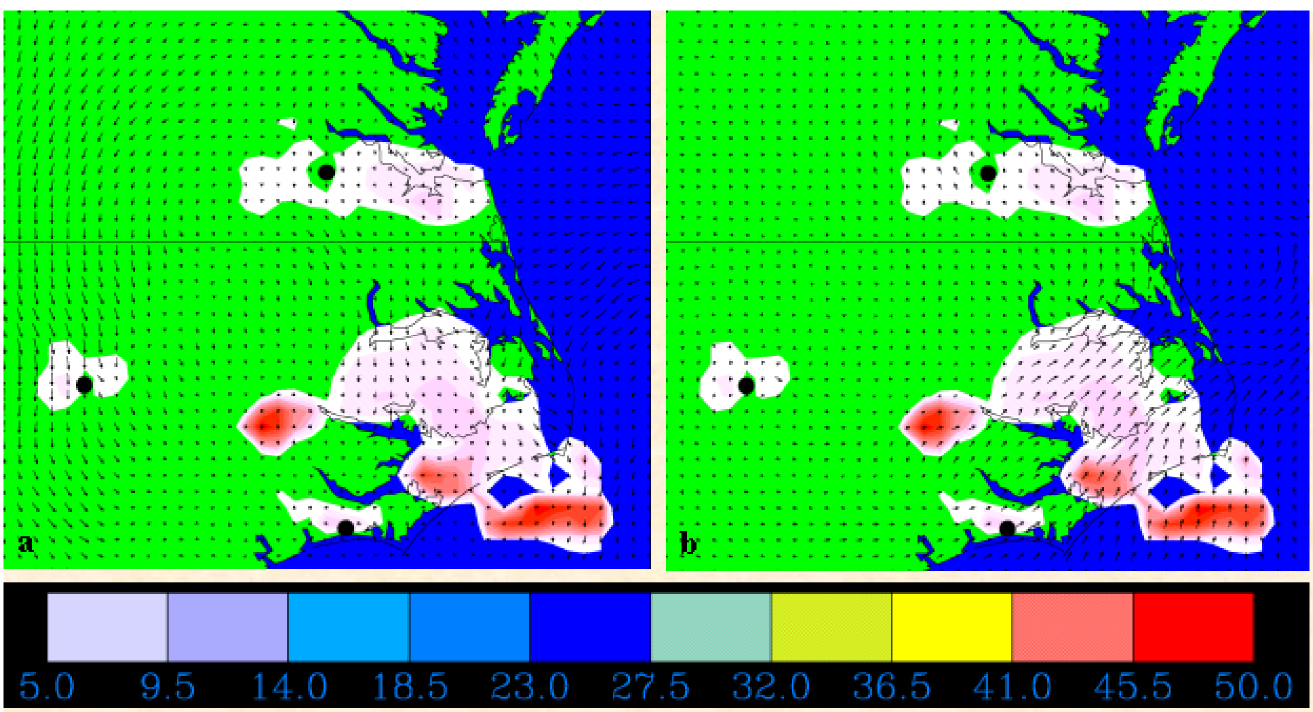

Figure 3. Observed composite radar reflectivity (dBZ) and horizontal wind differences between EXP and CNTL at 250 hPa (a) and 500 hPa (b), respectively, at 01 UTC 10 May 2003.

IMPACT

The ADAS cloud analysis and the 3.5DVAR wind analysis systems that use geostationary satellite data, surface observations and radar measurements running in real-time with the COAMPS-OS will provide the Navy, through NRL NOWCAST system, with near real-time, three-dimensional cloud and wind analyses in any region of interest to support the Navy's mission. The technology was demonstrated during Fleet Battle Experiment – Juliet with products providing up-to-date, detailed information to tactical decision makers about the three-dimensional atmospheric battlespace conditions. This information is simultaneously assimilated into the high-resolution COAMPS model to improve short-term theater-scale weather prediction. The high-resolution winds from both the data assimilation system and the COAMPS model forecast are also used to drive chemical/biological (CB) dispersion models, which are used for assessing contamination avoidance and decontamination strategies. While focusing on battlespace environmental applications, this work also establishes a scientific framework for utilizing radar-derived meteorological information in nowcasting and numerical weather prediction applications.

TRANSITIONS

The ADAS cloud analysis and cloud verification system has been successfully integrated into COAMPS-OS 1.2 in 6.4 programs (PE 0603207N, SPAWAR PMW-150). The ADAS cloud verification algorithms and associated source codes have also been adapted by COAMPS Verification System for cloud verification.

RELATED PROJECTS

Related NRL base projects include BE-35-02-19, Data Assimilation and Analysis; BE 033-03-42, Multidimensional Data Assimilation Methodologies, and BE 35-2-56, Nowcasting the Atmospheric Battlespace Environment. Other related projects at NRL are funded by ONR (Nowcast for the Next Generation Navy) and SPAWAR PMW-150, task X2342 under PE 0603207N (Variational Assimilation and Physical Initialization; On-Scene Tactical Atmospheric Forecast Capability).

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